International Journal of Scientific & Engineering Research, Volume 9, Issue 10, October-2018
ISSN 2229-5518

COMPARISON OF SURFACE REFRACTION AND UPHOLE REFRACTION METHODS IN THE DELINEATION OF LOW VELOCITY LAYER IN PARTS OF NIGER DELTA

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ABSTRACT --- The aim of the research is to determine the thickness of the weathered layer and their corresponding velocities, using the Uphole survey and the Surface refraction survey and to compare the two in order to ascertain the more reliable method. In twenty-seven (27) locations within Niger Delta, Nigeria, Surface refraction and Uphole refraction surveys were carried out. The weathered layer seismic refraction Uphole data and that of the Surface refraction data gotten from each location were computed and analyzed. From the analyses, the minimum velocity for Uphole diffraction is 213ms^{-1} while the maximum velocity for Uphole diffraction is 781ms^{-1}. The average Uphole velocity across the 27 sites is 504.81ms^{-1}. For surface diffraction, the minimum velocity is 242ms^{-1} while the maximum velocity is 763ms^{-1}. The average surface diffraction velocity across the 27 sites is 499.78ms^{-1}. Comparatively, it is observed that the Uphole velocities are slightly higher than surface diffraction velocities in most of the sites. The average Uphole diffraction velocity of 504.81ms^{-1} is also higher than the average surface velocity of 499.78ms^{-1} across the 27 sites. Also from the analysis, the minimum thickness for Uphole diffraction is 8.10m, while the maximum thickness is 20.00m. The average thickness is calculated to be 14.62m. For the Surface diffraction weathered layer, the minimum thickness is 8.00m while the maximum thickness is 19.5m. The average weathered layer thickness from surface defection is found to be 14.49m. Comparatively, average weathered layer thickness of 14.62m gotten from Uphole detection, is higher than 14.49m gotten from the Surface diffraction method.

Both refraction methods are reliable and the results are very similar, the delay experienced in Surface refraction may be due to shot point offsets, which can be corrected. Notwithstanding, the Surface refraction method is far more cost efficient than the Uphole method. The velocities and thicknesses are entirely in the weathered layer, this indicates that the foundation of Engineering structures in the locations must be above the maximum thickness of 20.00m. The results can also be used for risk assessment, underground water exploration and seismic static corrections in the area.

Keyword --- Seismic, surface and uphole refraction, weathered layer, consolidated layer, shot point, velocity-depth, lithology, Niger Delta, Nigeria

INTRODUCTION

The weathered layer is the shallow subsurface layer of the earth which is composed of loose materials such as sand, gravel and soil in their unconsolidated form. The composition is heterogeneous in form and it is characterized by low seismic velocity. This is responsible for the delay experienced in travel-time of seismic waves in the layer [1],[2].

The weathered layer is also characterized by high porosity, lack of cementation, low pressure and low bulk modulus. These properties are responsible for the very low seismic wave velocities recorded in the layer. The base of the weathered layer forms an interface between the weathered layer and the consolidated layer [3]. Since the consolidated layer is of interest not only for geophysical survey in seismic reflection activities but also for structural engineering purposes, the accurate determination of the velocity and thickness of the overlying low velocity layer is important.

Theoretical Background to Seismic refraction Principle

For the seismic refraction method to be used in the determination of the properties of the subsurface, the time of arrival of the generated wave and the offset distance must be determined. The path and velocity of the wave are estimated using the information gotten from the refracted ray across layer boundaries with variation of formation properties. The critically refracted signal travels down through the different layers before returning back to the surface to be successfully detected by the line of geophones.

In refraction seismic work, since the parameter of interest is the time from source to the receiver of the pulse at a certain distance, in the interpretation of the data we only need to know the travel times, for the first arrivals (head wave) and the distance to the geophone (Figure 1).

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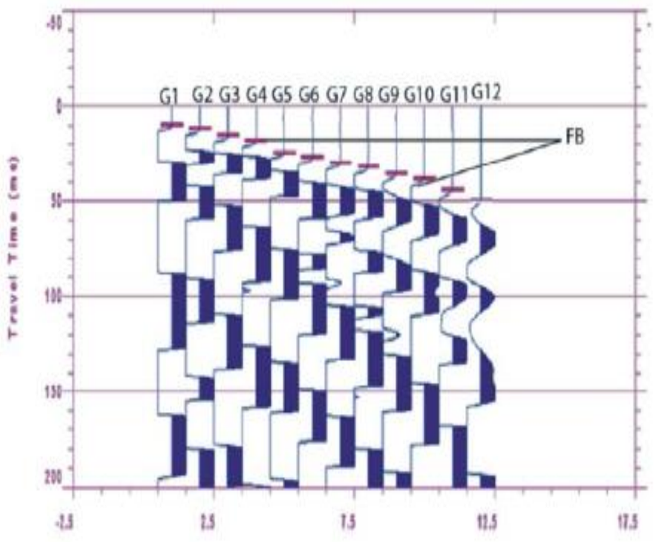

Figure 1: Seismic trace showing first breaks (FB) with geophones positions (G) [4]

A two, three or multiple layer case is possible;

A Two Layer Case

A horizontal plane layer with velocity V_1 resting on top of a layer with velocity V_2, after the shot, the direct wave will arrive first. At the cross over distance, X_c the direct wave and the headwave will be registered at the same time. At distances greater than X_c, the headwave will be the first to arrive.

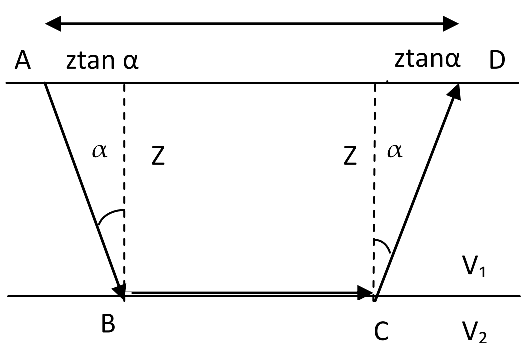

Figure 2: Headwave travel path

Where;

Z = Perpendicular distance from the shot to the interface down-dip,

V_1 = First layer velocity V_2 = Second layer velocity

$i_c = \alpha =$ Incident angle

By plotting the arrival times with the offsets and the best fitted straight line is drawn through the points, the velocity and thickness of the top layer(s) as well as the velocity of the infinite layer.

Using the relationship between the travel times for the direct wave and refracted wave, we get the equation for the depth, Z of the low velocity layer.

The total refracted distance = AB + BC + CD

$AB = CD = \frac{Z}{Cos\ \alpha}$, $BC = X - 2\tan\alpha$, $\sin\alpha = \frac{V1}{V2}$,

The total time t along the refracted path ABCD is deduced to be

$$t = \frac{2Z}{V_1 V_2}\left(V_2^2 - V_1^2\right)^{1/2} \qquad (1)$$

And,

$$Z = \frac{t_i}{2}\left(\frac{V_2 V_1}{\left(V_2^2 - V_1^2\right)^{1/2}}\right) \qquad (2)$$

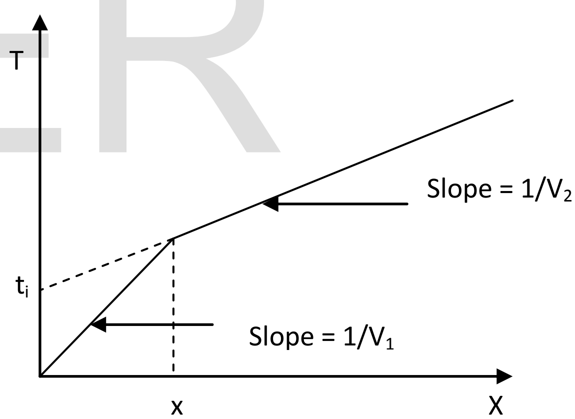

Figure 3: Time-distance plot for a horizontal

In the calculation of the depth Z, an alternative method is to use the crossover distance X_c. At Xc, the time taken by the direct wave to arrive at the geophone is equal to the time taken by the headwave to arrive at the same geophone. Hence, the depth Z can be shown to be;

$$Z = \frac{X_c}{2}\left(\frac{V_2 - V_1}{V_2 + V_1}\right)^{\frac{1}{2}} \qquad (3)$$

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A Three Layer Case

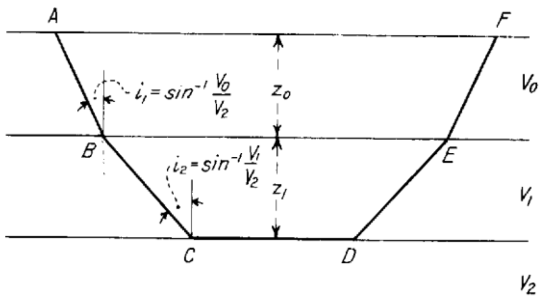

Figure 4: Three layer refraction

A three layer case with velocities V_o, V_1 and V_2 ($V_2 > V_1 > V_0$) as shown above in Figure 4, the ray corresponding to the least travel time makes an angle i_1 with the vertical in the uppermost layer and an angle i_2 with the vertical in the second layer, i_2 is also the critical angle for the lower interface. The expression for the total travel time from A to F is

$$T = \frac{x}{V_2} + \frac{2z_0\sqrt{V_2^2 - V_0^2}}{V_2V_0} + \frac{2z_1\sqrt{V_2^2 - V_1^2}}{V_2V_1} \qquad (4)$$

Second layer thickness Z_1 is shown as;

$$Z_1 = \frac{1}{2}\left(T_{i2} - 2z_0\frac{\sqrt{V_2^2 - V_0^2}}{V_2V_0}\right)\frac{V_2V_1}{\sqrt{V_2^2 - V_1^2}} \qquad (5)$$

Where Z_0 = the thickness of the 1st layer, Z_1 = the thickness of the 2nd layer

The depth to lower interface is the sum of Z_1 and Z_0, $Z = Z_0 + Z_1$ also given as;

$$Z = \frac{t_i}{2}\left(\frac{V_2V_1}{\left(V_2^2 - V_1^2\right)^{1/2}}\right) \qquad (6)$$

Multilayer Case

As long as the speed in each layer is higher than that in the one just above it, the derived time relation in a two and three layer case can be extended to other multiple layers. Cross-over distance for each layer increases with its depth. The slope of each segment is simply the reciprocal of the speed in the layer if the wave has travelled along it horizontally. While the intercept time of each segment depends on the depth of the interface at the bottom of the corresponding wave path and on the depths of all those interfaces that lie above it in the section [5].

Uphole Refraction Survey

An uphole survey normally requires taking a shot on the surface, or in a small hole excavated on the ground, and recording the refracted wave response via a geophone/hydrophone suspended at certain intervals in a vertical column bore into the weathered layer [3].

The hydrophones and geophones used detect the arrival time and give information from source depth. Typical uphole survey acquisition geometry is given below in Figure 5

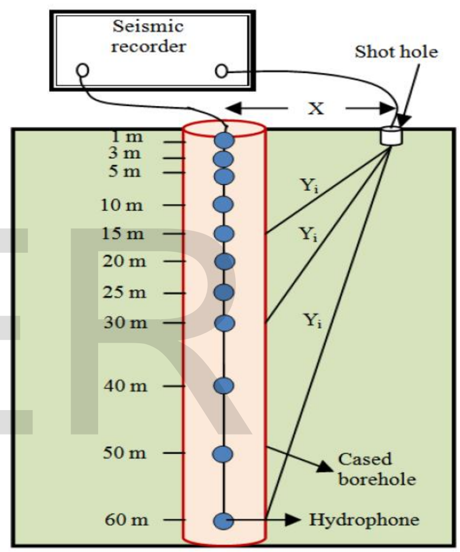

Figure 5: Schematic diagram of downhole technique

The depth versus time signals of the arrival seismic wave is used in the generation of an uphole plot, which clearly shows velocity variation with depth. From the graph below, the slope of line 1 (L1) gives $1/V_1$ while that of line 2 (L2) gives $1/V_2$. The seismic refraction velocities of the various subsurface formation layers are determined from the respective slope.

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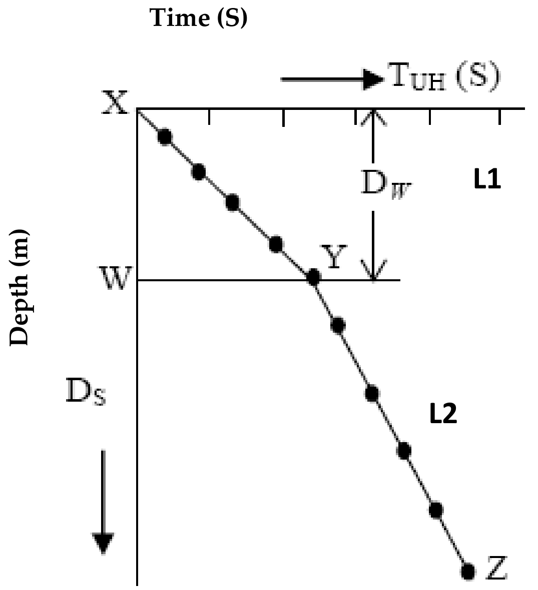

Figure 6: Typical Uphole survey time depth relationship

The reciprocal of the slope of line 1 in the graph, represents that of the unconsolidated low velocity layer while that of line 2 represents the velocity of the underlying consolidated layer.

The depth to the base of the low velocity layer was determined from the line intercepts (t_1) of the time axes using the relation [6].

$$Z = \frac{\tau_1 V_1 V_2}{2\sqrt{V_2^2 - V_1^2}} \qquad (7)$$

Where: Z = The depth of the weathered layer, V_1 = The velocity of the weathered layer

V_2 = The velocity of the underlying consolidated layer

t_1 = The intercept of the second segment of the straight line graph

LOCATION OF STUDY

The location of study is the freshwater swampy region of Niger Delta. The swamp region of the Niger Delta occupies an area situated between latitudes 4° to 6°N and longitudes 4° to 9°E (Figure 7), with the Gulf of Guinea acting as the continental margin in the equatorial region of West Africa. It covers a geographical area of about 259,000 km². Its sub-aerial encompasses about 75,000 km² and extends 300 km across East to South [7]. It is situated at the southern end of Nigeria, made up of mangrove swamps and fresh water swamps with relief that increases toward the north. The sediments coarse upward with increasingly regressive sequence that attains a maximum average thickness of 35,000 feets[8]. The regressive sequence is of clastic sediments which has off-lap deposition cycles, interrupted by variation of sea level [9].

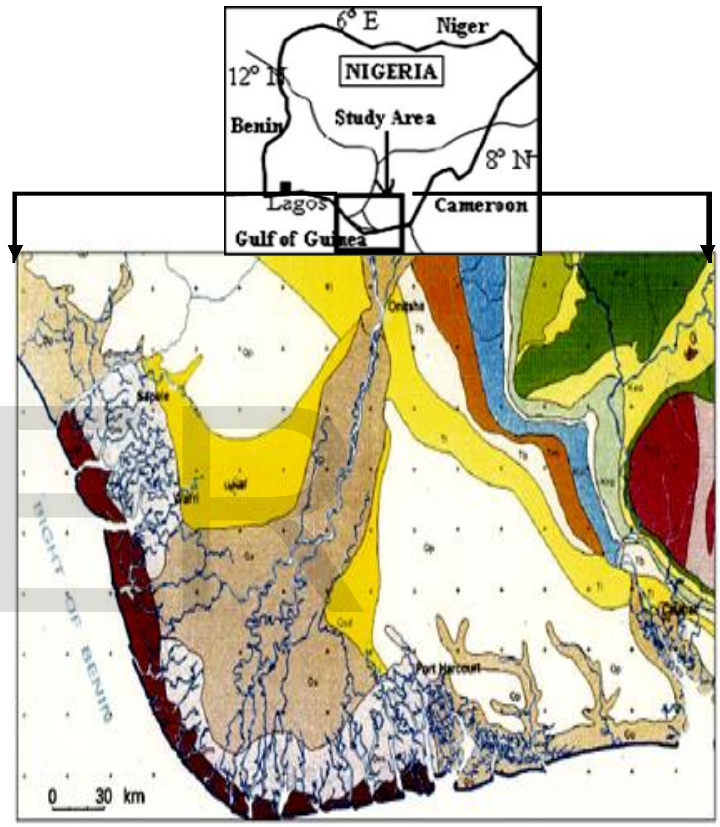

Figure 7: Location of Study Area Showing Geological map of the Niger Delta and Surroundings [10]

MATERIALS AND METHOLOGY

Acquisition of Uphole Data

The uphole design comprised a single hydrophone unit secured on a cable and suspended at the lower end by a heavy metal. Calibration of the cable was done at regular interval and logged up to twenty four (24) channels.

The calibrated regular intervals used were in the range of 1m to 60m at depth difference 1m for shallow depth (1m – 6m) and 3m for depth ranging from 6m downward. The uphole points were located at the established seismic lines. Each uphole location is bored to 60m, using rotary method and flushed continuously for some minutes to enhance

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stability with smooth and effective casing. During drilling, samples from the formation were collected at every 3m depth interval. Thereafter, hydrophone spreads consisting of 24 hydrophones points were suspended in the drilled hole to a depth of 60m.

Plastic casings were installed in the hole to minimize interference of the formation with the hydrophone strings. A cylindrical weight of 5kg was attached to the suspended cables of hydrophone spread to keep it floating upright in the borehole. The seismic refraction energy source was generated by small explosions of a dynamite of mass 0.25kg buried 1m deep at an offset distance of 2m from the surface of the uphole position. After explosion, the uphole data were acquired by the hydrophone receivers in the borehole covering depth 1.0m to 60m.

The variation in depths of the dynamite shootings was to ensure that the shot point and the receiver point were not at the same datum, to make for easy observation of first breaks and other noticeable signals including the delayed events. McSeis-160MX seismograph data recording instrument was used in the survey.

Uphole Data Processing

From the recorded traces, the first breaks on the seismograph were picked. The files were processed with Abem Terraloq Processing device to handle the digital waveform data obtained by seismographs. The first and second layer velocities were filtered using velocity model function with a specified window length which was determined according to the degree of smoothness required. The picked travel times were corrected to account for the 2m offset distance from the seismic source to the borehole head. This correction approximates as though the data were recorded with the seismic source placed exactly at the borehole head.

The recorded travel times were plotted against the source-receiver distance. The graphs were plotted for each uphole points and the layer velocities and thicknesses were obtained.

The slopes of the two layers were automatically calculated and the reciprocal of the slopes gave the velocities of the weathered and consolidated layers. The depth to refractor (thickness) was also calculated from the point of intersection of the slopes. This was done for all the shot points. The classification of the different lithologic sediments into grain sizes was carried out using the standard proposed by Wentworth. A sample of the plot of time-distance graph with well log reflecting lithology is as shown in Figure 8.

The Microsoft excel was used to generate the plot of velocity of weathered layer versus depth of the weathered layer, and to generate comparative plots of surface refraction and uphole refraction for velocities and thickness.

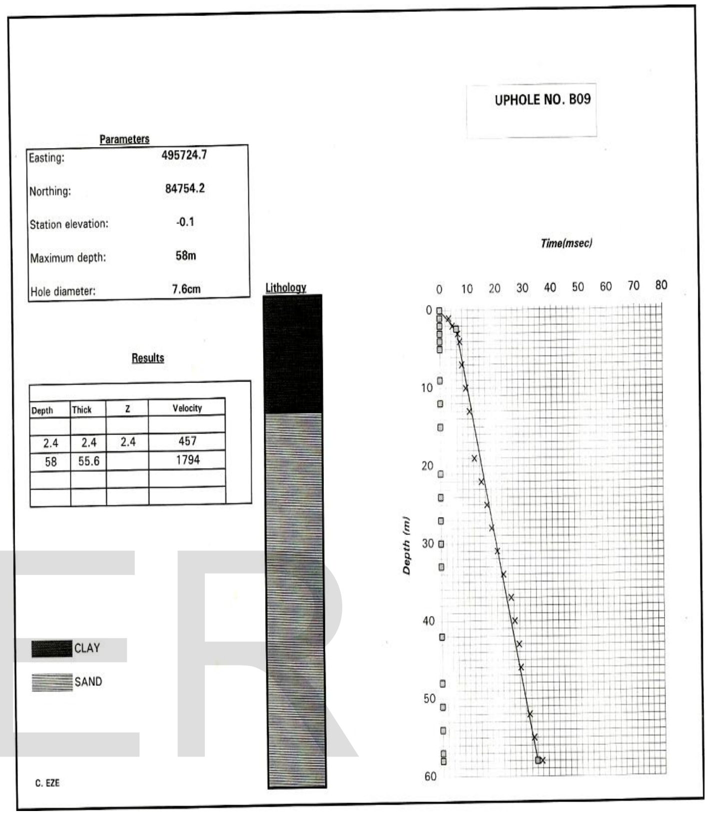

Figure 8: Lithology variation with uphole from one of the site

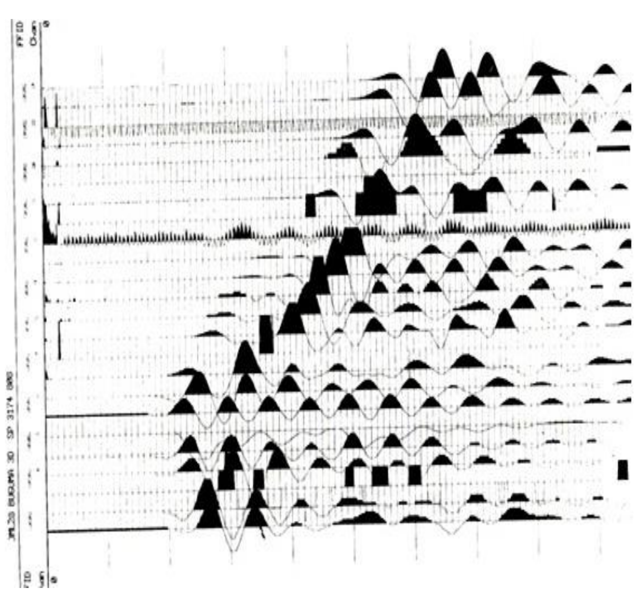

Figure 9: Monitor record from the Uphole detector in selected area

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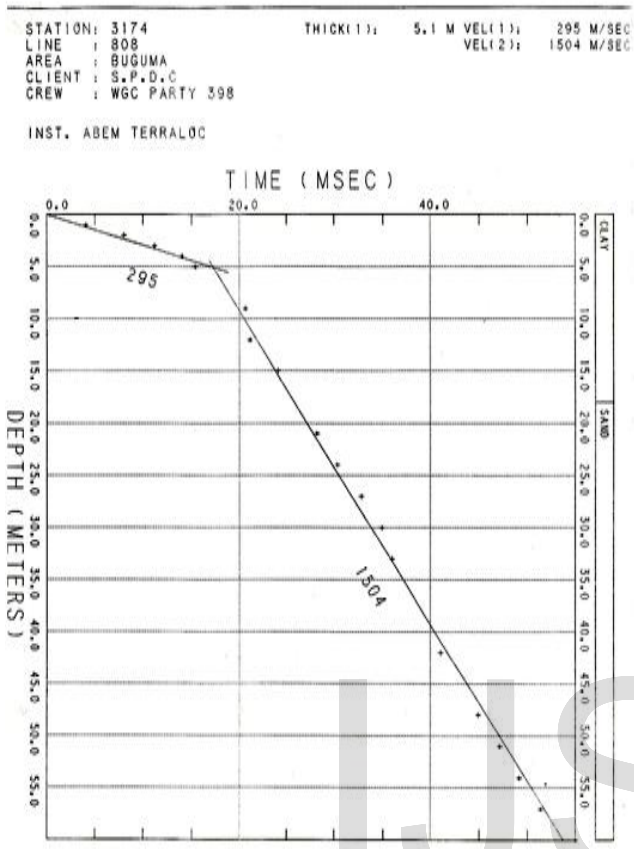

Figure 10: Time versus Depth Uphole plot from selected sites

Acquisition of Surface Refraction

The typical field set up for surface seismic refraction method is as shown below in figure 8. 12 geophones were laid out on ground. The spacing of the geophones was as shown on the diagram. Three shots of 0.2kg dynamite were fired simultaneously from offsets of 5m, 70m and 135m, to check for accuracy. For the direct and reverse shot, the average result was taken as the required velocity of the medium.

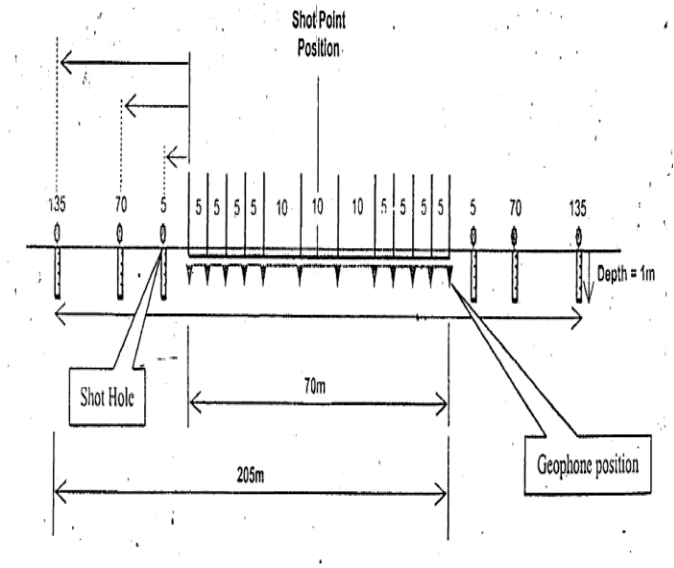

Figure 11: Typical geophone layout on horizontal array used for the location

Figure 12, shows one of the surface detector refraction monitor record from the location. From the traces of the monitor record of each location, arrival times were picked and utilized in computing the velocities.

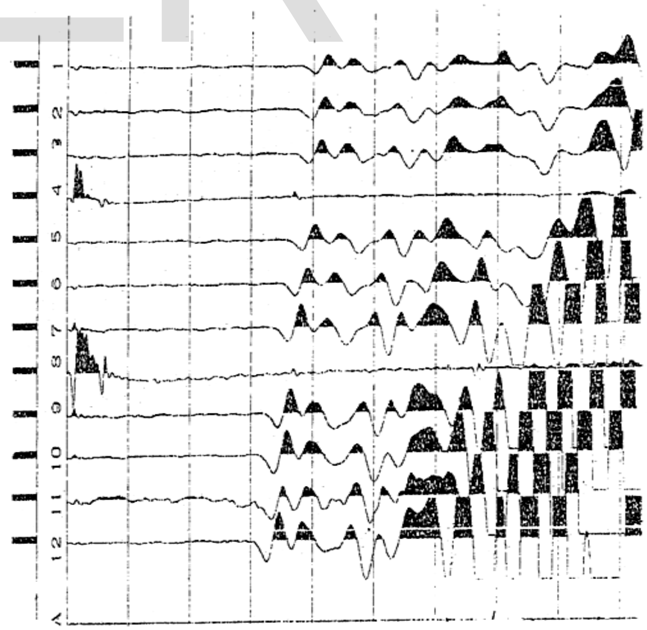

Figure 12: Surface detector refraction monitor record from

the study area

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RESULTS AND DISCUSSION

In the study area, twenty-seven locations with hydrophone and geophones arrays, with each location having twelve geophones for the surface refraction and twenty-four hydrophones for the downhole refraction, the data were collated and analyzed.

Twenty-seven (27) weathered layer data were randomly selected from the location, comprising 27 surface refraction data and 27 downhole refraction data, each having velocity and a corresponding thickness. The average weathered layer velocities and average thicknesses across the locations are tabulated in Table 1.

Velocity Comparison; The velocity variation across the 27 sites is as shown on the Figure 10 and Figure 11. They both show similar variations with downhole diffraction velocities slightly higher than that of surface refraction velocities. The minimum velocity for downhole diffraction is 213ms^{-1} while the maximum velocity for downhole diffraction is 781ms^{-1}. The average downhole velocity across the 27 sites is 504.81ms^{-1}.

For surface diffraction, the minimum velocity is 242ms^{-1} while the maximum velocity is 763ms^{-1}. The average surface diffraction velocity across the 27 sites is 499.78ms^{-1}. This is closely shown on figure 12.

It is observed that the downhole velocities are slightly higher than surface diffraction velocities in most of the sites. The average downhole diffraction velocity of 504.81ms^{-1} is also higher than the average surface velocity of 499.78ms^{-1} across the 27 sites.

Thickness Comparison: For the downhole detector weathered layer, the minimum thickness occurs at location 21 with a value of 8.10m, while the maximum thickness occurs at location 27 with a thickness of 20.00m. The average thickness is calculated to be 14.62m. For the surface detection weathered layer, the minimum thickness is 8.00m which also occurs at location 21, the maximum thickness is 19.5m at location 27. The average weathered layer thickness from surface defection is found to be 14.49m. As shown in Table 4.1.

Comparatively, average weathered layer thickness of 14.62m gotten from downhole detection, is higher than 14.49m gotten from the surface diffraction method, as closely shown in Figure 13.

Challenges of Uphole Refraction Survey over Surface Refraction Survey

It is observed that the uphole refraction survey have the following challenges over the surface refraction method.

1. Uphole method requires drilling resources like drilling rig, water, tanker etc. which are not required in surface refraction survey.

2. Uphole method takes comparably longer time for the drilling process to get achieved while time taken for surface refraction is lower.

3. Requirement of other resources like pulley, pulley stand, charge holder, shooting wire and more manpower characterizes uphole refraction survey thereby making it more tedious, time consuming and more expensive than surface refraction surveys.

4. In uphole survey, drilling process changes the lithology in the vicinity of the borehole due to formation of mud cake, this could affect the speed of seismic wave propagation in the formation, while surface refraction survey do not require any mud cake.

5. Uphole method gives the near surface information at the point of survey only and not much information in lateral direction while surface refraction survey gives the information about the near surface over the length of the laid spread.

6. Possibility of human error while loading and firing the charge, wrong reading and data loss due to misfires in simultaneous loading methodology characterizes uphole method.

7. If separate and successive loading and firing methodology is adopted, man power requirement increases considerably for uphole refraction..

8. Requirement of considerable time for uphole survey operation hamper and slows down the process of seismic data acquisition while surface refraction is easy to accomplish, time efficient and more economic (costs one-sixth of the uphole survey)[11].

9. Abandoning of the operation due to collapse of borehole is possible with uphole method.

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Advantage of Uphole Refraction Survey over Surface Refraction Survey

1. Uphole survey gives information about the lithology of the lateral formation which can be used in comparison with the drilled formation extraction to better characterize the layer. Surface refraction gives no information on lithology variation.

2. Uphole data can be processed by any available software and can be interpreted manually. In case of surface refraction survey, dedicated software is required for data processing and interpretation of large data set.

3. Surface refraction survey may be misleading, if a low velocity layer is encountered between two high velocity layers. A thin LVL is usually lost in refracted first break times, hence depth of layers may be miscalculated, this is very unlikely in uphole refraction survey.

4. Surface refraction survey may not distinguish between two layers if velocity anomaly between them is not appreciable, while uphole survey will clearly show the two layers

CONCLUSION AND RECOMMENDATIONS

Conclusion; From the results obtained, the following conclusions were made;

1. For the downhole detector weathered layer, the minimum thickness is 8.10m, while the maximum thickness is 20.00m, the average thickness is 14.62m. For the surface detection weathered layer, the minimum thickness is 8.00m, the maximum thickness is 19.5m. The average weathered layer thickness is 14.49m. This shows the need for weathered layer correction, since the research did not consider the point at which the consolidated layer began. The determined depth is not enough to estimate the depth point at which structures can be erected in the area.

2. Comparatively, the average downhole diffraction velocity of 504.81ms^{-1} is higher than the average surface velocity of 499.78ms^{-1} across the 27 sites. Also, the average weathered layer thickness of 14.62m gotten from downhole detection is higher than 14.49m gotten from the surface diffraction method. The disparity could be as a result of the shotpoint offset correction which may be causing a delayed arrival or lower velocity in the same formation as observed in the surface refraction which appears slower than the uphole method.

Recommendations; From the results obtained, the following recommendations were made;

1. Since the velocities are far below the expected minimum velocity of 1500ms^{-1}, required for a firm engineering and structural foundation in the area, there is need for weathered layer correction for any structure intended to be constructed in the area, in order to get to the consolidated layer.

2. With shotpoint correction, the surface detection slightly proves to be more reliable than downhole detection from the analysis of the samples gotten, hence its use is recommended.

3. Both surface diffraction method and the uphole diffraction method are reliable but surface diffraction method is more cost efficient and easier to undertake. Therefore in places where well log data are available and lateral formation study is not of keen interest, surface refraction can be undertaken, however if they are of interest Uphole refraction is a better alternative.

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ISSN 2229-5518

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Table 1: Average weathered layer velocity and thickness for both the surface refraction and downhole refraction from each location.

Location	**Downhole Detector Weathered Layer Velocity (ms^{-1}) $(V_0)_{dd}$**	**Surface Detector Weathered Layer Velocity (ms^{-1}) $(V_0)_{sd}$**	**Modulus of Velocity Difference $\lvert(V_0)_{dd}-(V_0)_{sd}\rvert$**	**Downhole Detector Weathered Layer Thickness (m) $(Z_0)_{dd}$**	**Surface Detector Weathered Layer Thickness (m) $(Z_0)_{sd}$**	**Modulus of Thickness Difference (m) $\lvert(Z_0)_{dd}-(Z_0)_{sd}\rvert$**
1	576	560	16	16.05	16.00	0.05
2	446	423	23	14.28	14.30	0.02
3	417	486	69	13.04	13.00	0.04
4	428	438	10	13.36	13.00	0.06
5	696	682	14	18.30	18.25	0.05
6	410	430	20	13.65	13.70	0.05
7	309	300	9	11.91	11.70	0.21
8	500	442	58	15.50	15.60	0.10
9	405	369	36	13.00	12.93	0.07
10	492	478	14	14.80	14.70	0.10
11	745	687	58	18.30	18.25	0.05
12	573	581	8	16.00	15.00	1.00
13	377	360	17	12.94	13.00	0.06
14	282	266	16	10.00	9.10	0.90
15	651	670	19	16.66	16.50	0.16
16	539	523	16	14.80	14.70	0.10
17	359	351	8	13.00	13.10	0.10
18	672	663	9	17.00	17.10	0.10
19	589	609	20	15.78	15.80	0.02
20	419	449	30	13.36	13.06	0.30
21	213	242	29	8.10	8.00	0.10
22	304	298	6	10.66	10.60	0.06
23	608	588	20	16.05	16.10	0.05
24	556	552	4	15.00	14.90	0.10
25	661	670	9	16.80	16.72	0.08
26	622	614	8	16.50	16.30	0.20
27	781	763	18	20.00	19.50	0.50
Average	504.81(ms^{-1})	499.78(ms^{-1})		14.62 (m)	14.49 (m)	

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ISSN 2229-5518

Measurement

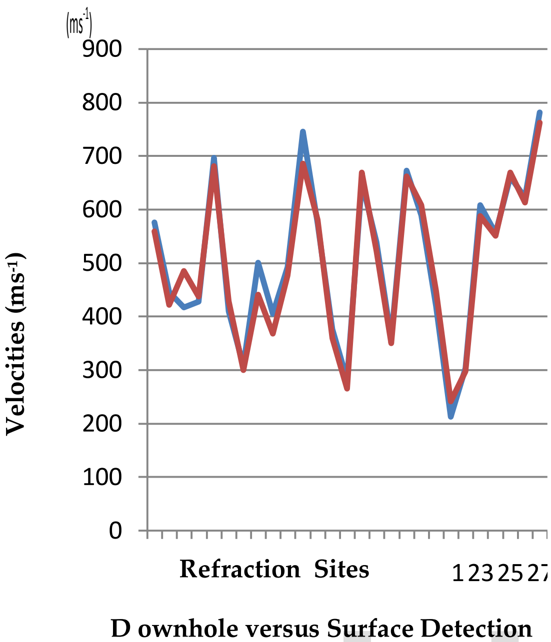

Figure 13: Surface detection versus downhole detection velocity variation across the fields

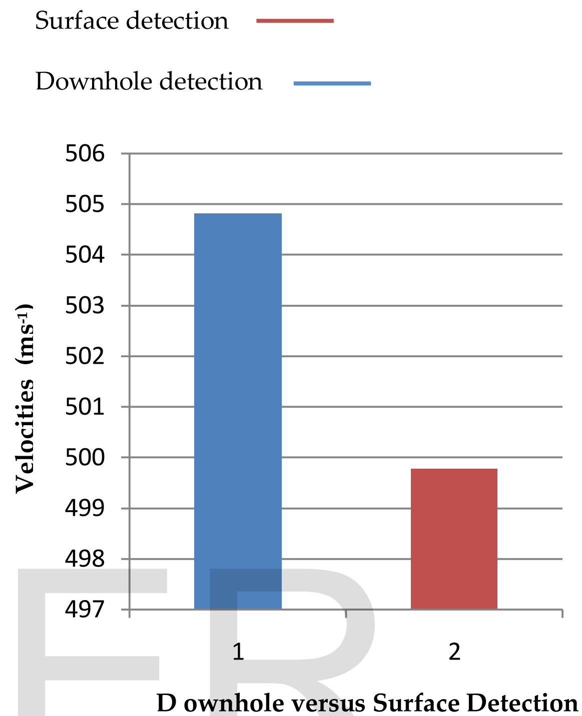

Figure 15: A close plot showing difference in the average velocities between 1. Dowhole detection 2. Surface detection

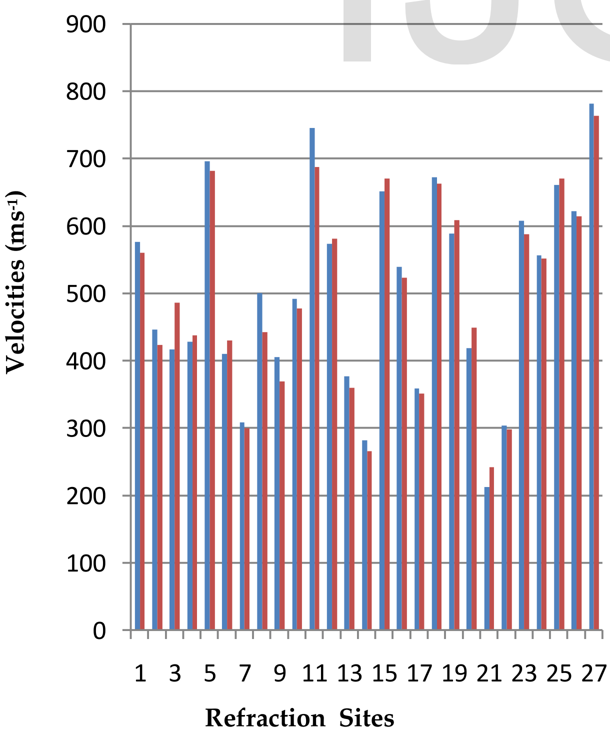

Figure 14: Surface detection (brown) versus Downhole detection (blue) Velocity variation across the fields on bar chart

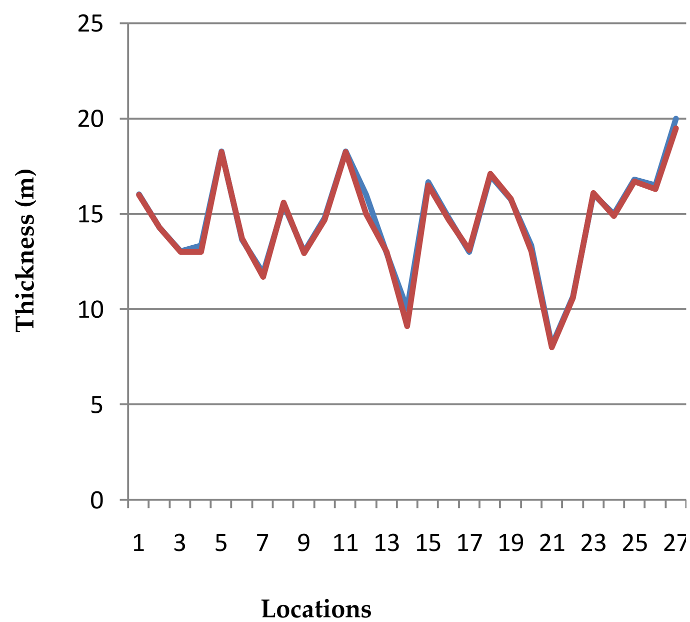

Figure 16: Comparison of Surface detection versus downhole detection thickness variation